Title: Intelligent Monitoring System With High Temperature Distributed Fiberoptic Sensor For Power Plant Combustion Processes

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Abstract

Objectives and Scope

The objective of the proposed work is to develop an intelligent distributed fiber optical sensor system for real-time monitoring of high temperature in a boiler furnace in power plants. Of particular interest is the estimation of spatial and temporal distributions of high temperatures within a boiler furnace, which will be essential in assessing and controlling the mechanisms that form and remove pollutants at the source, such as NOx. The basic approach in developing the proposed sensor system is three fold: (1) development of high temperature distributed fiber optical sensor capable of measuring temperatures greater than 2000 C degree with spatial resolution of less than 1 cm; (2) development of the boiler furnace monitoring model; and (3) development of an intelligent estimation theory for real-time monitoring of the 3D boiler temperature distribution.

Accomplishments To Date

Fiberoptic sensor development:
1) Improve the performance of in-fiber grating fabricated in single crystal sapphire fibers. In the first year, we have successfully fabricated in-fiber gratings in single crystal sapphire fibers by precisely dicing the sapphire fiber with a high accuracy diamond saw. The grating fabricated by this method proves the concept of harsh environment distributed fiber optic sensor based on in-fiber gratings fabricated in single crystal sapphire fiber. However, mechanical dicing saw has a limited position accuracy (around 0.5 micron), which limits the overall quality and performance of in-fiber gratings. In the second year, we have investigated two new approaches for grating fabrication. One is based on periodic heating by a focused CO_2 laser, and the other one is based on plasma etching. Much better spatial accuracy (around nm range accuracy) can be achieved by these new approaches.
2) Test the grating performance of single crystal sapphire fiber with new fabrication methods. We have tested the performance of grating fabricated by diamond saw dicing and periodic heating induced by a focused CO_2 laser beam. Spectral response of grating is changed as the ambient factors (such as ambient refractive index) changes. Thus, our fabricated gratings can be used for harsh environment distributed fiber optic sensors. Key parameters of grating, including spectral width, maximum attenuation, noise level, are quantitatively measured, which provides a useful guidance for the future development of in-fiber grating technology in single crystal sapphire fibers.
3) Apply the fabricated grating to high temperature sensor. We have applied the fabricated fiber grating to high temperature distributed sensing systems. Indeed, we observed the change of spectral response of grating as the ambient temperature changes. Thus, we have experimentally proven that this grating can be used for high temperature distributed sensing systems.

Boiler furnace monitoring model development:
In the first year, the effort was primarily to get a functional workstation, with CFD software, into place and to train the student on its application to multi-dimensional combustion simulation. The workstation acquired for this project comprises dual-Xeon 2.0 GHz processors and 512 MB RAM. A license for FLUENT 6.1 was been obtained. The graduate student was trained with FLUENT to achieve the goals of this project with regard to multi-dimensional simulation. In the second year, we are now working with a 2-D model of the Down Fired Combustor and a 3-D model of the Demonstration Boiler. Modeling the DFC has provided the graduate student the opportunity to become skilled using FLUENT, to leverage existing grids and extensive prior experimental work for comparison. The

output from the DFC modeling will be temperature maps for use in training the predictive tool to describe the temperature distribution within the combustor to effect control actions.

Intelligent estimation theory development:
In the first year, intelligent state estimation theory was formulated to estimate the temperature distribution of furnaces. Since the fiberoptic sensors are one dimensional (1D), a theory was developed which will map the set of 1D (located judiciously within a 3D environment) measurement data into a 3D temperature profile. This theory presents a semigroup-based approach to the design and training of a system type neural network which performs function extrapolation. In the second year, the theory was implemented in neural network architectures. Because no analytic expression is available for either the composite system or the individual splines, neural networks are used to develop the model. However, unlike conventional neural network architectures, this approach follows semigroup theory which suggests that this particular mapping should be implemented as two mappings, requiring two cooperating channels of neural networks: the Function Channel and the Semigroup Channel. The function channel was designed by using Radial Basis Function neural networks and the semigroup channel was designed by using Elman Recurrent neural networks. The theory was tested in several engineering problems with simulated data and showed promise for future implementation with realistic physical data generated by the Fluent model.

Future Work

- In the 3rd year of this project, we will deploy our unique distributed fiberoptic sensor in a testing boiler. The measured data (such as temperature distribution) from the sensor will be used to intelligently control the performance of the boiler. A higher burning efficiency and lower pollution emission is anticipated.
- In the boiler furnace monitoring model development, subsequent applications of FLUENT to the Demonstration Boiler will focus on determining the means by which the output from the fiber optic sensor can be used to determine whether some control action is needed to reduce emissions (i.e., NOx). The detailed simulations will be intended to provide guidance on how to achieve the intelligent control over efficiency and emissions.
- The intelligent estimation theory will be tested by using realistic furnace data generated by FLUENT code. It will then implemented in our DFC furnace integrated with the fiberoptic sensor.

Technical Publications

1. Kun-wook Chung and Shizhuo Yin, “A highly nonlinear dispersion shifted fiber with 9.3 μm^2 effective area and low loss for all fiber wavelength converter,” Microwave and Optical Technology Letters,” pp. 153-156 (2004).
2. Kun-wook Chung, Sungwon Kim, and Shizhuo Yin, “Design of a highly nonlinear dispersion-shifted fiber with a small effective area by use of the beam propagation method with the Gaussian approximation method,” Optics Letters., Vol. 28, pp. 2031-2033 (2003).
3. Shizhuo Yin, Youwei Fu, and Sung-Hyun Nam, “An experimental investigation on electrically controlled wavelength selective holographic switch,” Optics Memory and Neural Networks, No. 2, pp. 131-138, 2003.
4. Wei-Hung Su, Hongyu Liu, Karl Reichard, Shizhuo Yin, and Francis Yu, “Fabrication of digital sinusoidal gratings and precisely controlled flats and their applications to highly accurate projected fringe profilometery,” Optical Engineering, Vol. 42 (6), pp. 1730-1740, (2003).
5. Shizhuo Yin, Sung-Hyun Nam, Jesus Chavez, Chun Zhan, and Claire Luo, “Innovative long period gratings: principles and applications (invited),” SPIE 5206-10, Aug., 2003.
6. S. Yin, Zhiwen Liu, Iam-Choon Khoo, Kun-Wook Chung, and Yi Yang, “Tunable photonic crystal fibers and their applications,” American Ceramic Society Meeting on Optical Waveguides: Unconventional Approaches and Applications, Oct, Corning, NY, 2003.
7. Sung-Hyun Nam, Jesus Chavez, and Shizhuo Yin, “Fabricating in fiber gratings in single crystal sapphire fiber,” SPIE 5350-8, San Jose, CA, Jan., 2004.
8. Kwang Y. Lee, John P. Velas, and Byoung-Hee Kim, “Development of an Intelligent Monitoring System with High Temperature Fiber-optic Sensor for Fossil-Fuel Power Plants”, accepted for presentation at the IEEE Power Engineering Society General Meeting, Denver, CO, June 6-10, 2004.

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